Spring 5-16-2014

Evaluation of Mangrove Ecosystem Restoration Success in Southeast Asia

Penluck Laulikitnont
University of San Francisco, plaulikitnont@gmail.com

This Master's Project

EVALUATION OF MANGROVE ECOSYSTEM RESTORATION SUCCESS IN SOUTHEAST ASIA

by

Penluck Laulikitnont

is submitted in partial fulfillment of the requirements
for the degree of:

Master of Science
in
Environmental Management

at the

University of San Francisco

Submitted:		Received:	
………………………………………..		………………………………………..	
Penluck Laulikitnont	Date	Gretchen Coffman, Ph. D.	Date

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Many restoration efforts have been implemented recently to offset the rapid degradation of mangrove ecosystem worldwide, especially in Southeast Asia where the largest area of mangrove ecosystem can be found. Two primary approaches used for mangrove ecosystem restoration include the plantation approach and the ecological mangrove restoration (EMR) approach. Monoculture plantation is the most common technique used in plantation approach, which usually results in low species diversity. The EMR approach on the other hand, focuses on correcting the hydrology of restoration sites first. Planting can be used as part of the adaptive management process if mangrove seedlings and propagules do not recolonize naturally. The lack of site understanding in project planning, the lack of project documentation, and the lack of monitoring data are the three main reasons for the failure of many mangrove ecosystem restoration projects as well as the inability to compare restoration approaches. Therefore, careful planning has to be implemented before restoration occurs. I documented previous attempts of both mangrove ecosystem restoration approaches and found that most of these attempts lacked scientific data to support their true effectiveness. As a result, I have developed a monitoring protocol for Southeast Asia to be incorporated into the final stages of every mangrove ecosystem restoration project. The protocol consists of overall site documentation and three levels of monitoring that includes: Level 1 – a transect based survey, Level 2 – monitoring of permanent plots, and Level 3 – sedimentation monitoring. The goal of developing this monitoring protocol was to use this to evaluate the success of each mangrove restoration project after restoration, use adaptive management techniques when projects are not on the correct restoration trajectory, and to eventually evaluate various mangrove ecosystem restoration approaches used in Southeast Asia.

EVALUATION OF MANGROVE ECOSYSTEM RESTORATION SUCCESS IN SOUTHEAST ASIA

1 INTRODUCTION

Mangrove forests are critical buffers between terrestrial and aquatic ecosystems in tropical climates worldwide. However, vast areas of mangrove ecosystem have been altered and lost due to various forms of development and agriculture over the past century. Two main approaches to mangrove restoration have been used throughout the world - the plantation approach and Ecological Mangrove Restoration (EMR) approach. In order to compare and evaluate the success of these approaches, monitoring data are needed to directly compare these approaches. Simple metrics used in monitoring other coastal wetland types can be measured to evaluate project success, including: survivorship of plants installed, native plant species diversity, percent cover and height of plants, sedimentation rates, water depths, and photo monitoring. If mangrove restoration projects evaluate these parameters over the first 10 years after construction, these data can be used to adaptively manage the restoration if one or more metrics are not meeting performance standards. Unfortunately, I have found that there has been very little monitoring of mangrove restoration projects using either approach. Therefore, I have developed a rapid assessment monitoring protocol to be incorporated as part of mangrove restoration projects in Southeast Asia in order to evaluate the success of each project and approach and adaptively manage these over time.

1.1 Definition of Mangrove

The term “mangrove” is used to define both the plants that occur in tropical tidal wetland forests and to describe the community itself. It is broadly defined as woody vegetation types occurring in both marine and brackish environments (Giesen et al. 2006). Mangrove ecosystems are made up of approximately 16 families and 40 to 50 species, including trees, palms, shrubs, vines, and ferns. Mangroves are highly specialized plants that have adapted to waterlogged saline soils subjected to regular flooding of the tides. According to Feller and Sitnik (2003), there are several different terms that are used interchangeably to describe the entire mangrove community. Examples of those terms are mangrove ecosystem, mangrove forest, mangrove swamp, mangrove community, and mangal.

1.2 Geographical Distribution of Mangroves

Mangroves are commonly found throughout 75 percent of the world's tropical coastline between latitudes 32 ° N and 38 ° S as illustrated in Figure 1 (Northern Territory Government 2002). Mangroves extend 10 ° to 15 ° farther south on the east coast of Africa, Australia, and New Zealand and 5 ° to 7 ° farther north in Japan, Florida, Bermuda, and the Red Sea. Oceanographic conditions that unusually move warm water away from the equator are the main cause of this extension of the mangrove area range (Odum et al. 1982). Giri et al. (2010) found that the total area of mangrove ecosystems in 2000 was 137,760 km^2 found throughout 118 countries and territories in the tropical and subtropical regions of the world. However, 75 percent of the world's mangroves are found in just 15 countries.

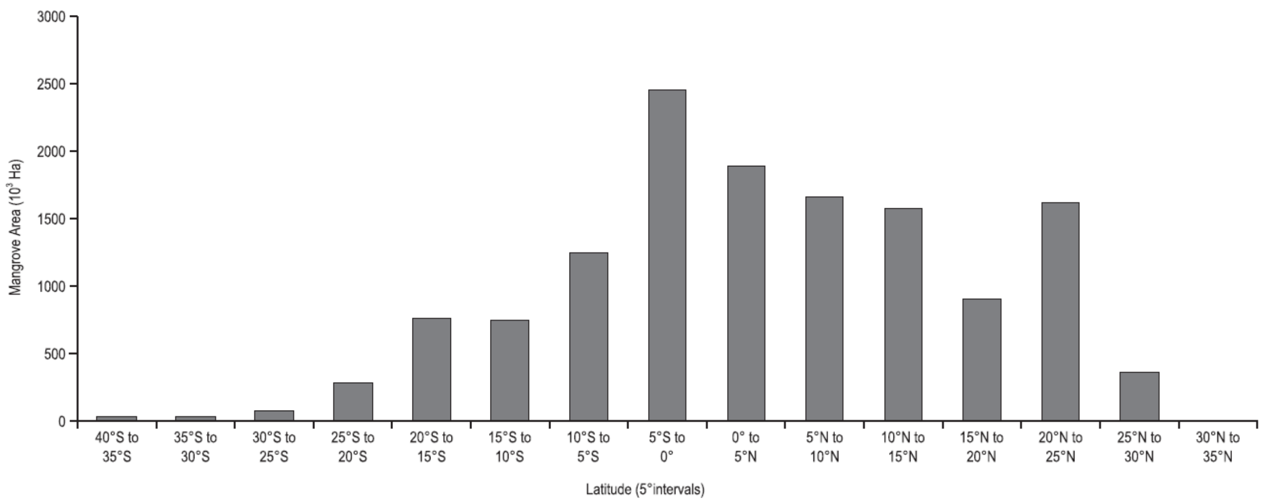


Figure 1. Latitudinal distribution of mangrove forests around the world (Giri et al. 2010)

1.3 Importance of Mangrove Ecosystem

Mangrove forests are indicators of healthy coastal ecosystems in tropical and subtropical climates worldwide. They are dynamic habitats linking land and sea. Important ecosystem services of mangroves include filtering pollutants to protect sea grasses and corals; protecting coastal ecosystem against storms and tsunamis; providing a critical food source for local communities; and sequestration of carbon (Barbier and Cox 2004, Sathirathai and Barbier 2001). In addition, mangroves also serve as breeding grounds and nursery habitats for marine organisms, an important ecological support function for many coastal and offshore fisheries. Moreover, local communities can use mangrove resources for their own benefits such as food, medicine, and fuel wood. However, overexploitation of these resources can result in the loss of mangrove ecosystem function and degradation (Vaiphasa et al. 2007).

1.4 Degradation of Mangrove Ecosystems

It has been reported that more than 50% of mangrove ecosystems have been significantly altered or destroyed in the last century due to human development (Quarto 2013). Biswas et al. (2008) identified six major causes of mangrove degradation in Asia: conversion to shrimp/aquaculture farms; conversion to sea salt farms; conversion to other agricultural practices; development of infrastructure; development of hydrological diversions; and alteration from natural disturbances. Figure 2 illustrates the major causes of mangrove degradation by various Asian countries. Giri et al. (2008) showed that conversion for agriculture was the most common cause of degradation of mangrove forests and aquaculture was the second most common throughout Southeast Asia.

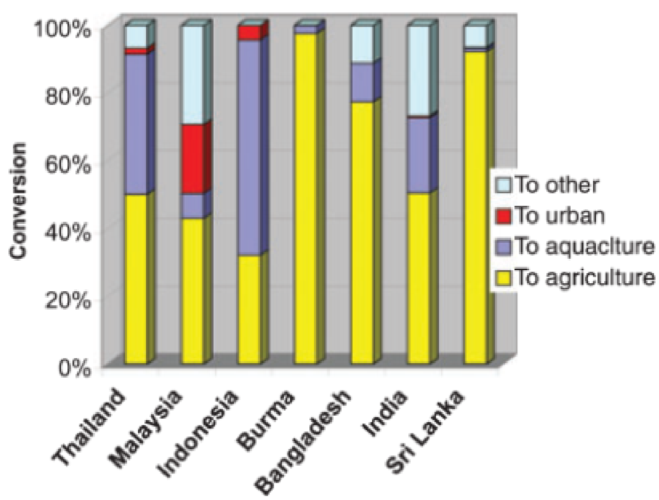


Figure 2. Major causes of mangrove degradation in Asia (Giri et al. 2008).

1.4.1 Mangrove Ecosystem Distribution in Southeast Asia

The largest mangrove area in the world can be found in Southeast Asia, occurring from the Irrrawaddy delta in northwestern Myanmar to the eastern part of Papua New Guinea. The total mangrove area spans about 6,000 km from east to west and 3,500 km from north to south in the region of Southeast Asia. Indonesia has the largest mangrove area in Southeast Asia (60%), followed by Malaysia (11.7%), Myanmar (8.8), and Thailand (5%). Moreover, the mangroves of

Southeast Asia are considered one of the most species-diverse in the world. 52 mangrove species can be found in Southeast Asia.

In the 1980s, there were approximately 6.8 million hectares of mangrove forest in Southeast Asia, which made up about 34-42% of the world's total area. However, the total mangrove area in Southeast Asia had dropped to less than 5.7 million hectares in 1990. This number represents about a 15% loss of mangrove ecosystem or a loss of 110,000 hectares per year for that time period. In 2003, almost 20% of the remaining mangrove area in Southeast Asia was incorporated into the region's protected area system shown in Table 1 (Giesen et al. 2006). Cambodia was the country with the highest percent of their mangrove forests protected at 48.8% of their 31,100 hectares.

Table 1. Mangroves located in the protected areas (PA) (Giesen et al. 2006).

Data Source:
**http://www.earthtrends.wri.org/*
***http://worldwildlife.org/biomes*
****Berdach 2004*

Year of Data Collection:
 # 2001
1997

Country	Protected Mangroves (ha)	% remaining mangroves in PA system ##
Brunei Darussalam	7 533	41
Cambodia	31 100 *	48.8
Indonesia	783 400 *	26.7
Malaysia	10 900 *	1.9
Myanmar	12 500 **	2.9
Papua New Guinea	106 300 *	24.6
Philippines***	347 ***	unknown
Singapore	45	0
Thailand	25 600 *	10.5
Timor-Leste	0	0
Viet Nam	1 600 * 43 115 #	1.5 39
Total	959 700	19.6

1.5 Mangrove Ecosystem Restoration

Quite a few restoration efforts have been implemented in the region as a result of the rapidly declining mangrove ecosystem extent and quality. Two main approaches have been used for mangrove ecosystem restoration: 1) the plantation approach and 2) EMR approach. Plantation restoration has been used as the primary technique for mangrove restoration worldwide.

According to Lewis III (2001), the plantation approach is inexpensive but does not usually succeed due to failure to understand the physiological tolerances of mangroves to tidal inundation. Mangrove species are often planted at the wrong elevation relative to tidal inundation. Some mangrove trees and other plants found in the landward zones of mangrove forests will die if they are they are inundated too long or exposed to air at low tide for too long. The EMR approach, on the other hand, can be done for similar or slightly higher costs in Southeast Asia if hand labor is used and is believed to be a more successful restoration approach with proper planning. However, Callaway and Zedler (2009) suggested that it is much easier and cheaper to preserve an ecosystem rather than restoring them.

1.6 Goals and Objectives

The goal of my research paper is to evaluate the success of two approaches used for mangrove restoration – the plantation approach and the EMR approach. Monitoring of plants, hydrology, soils and other ecosystem functions in mangrove restoration projects using both methods are needed to determine its true effectiveness. However, I have found that there are still very little monitoring data available for projects completed using either approach. Due to the lack of monitoring data for a comparison of these two methods, I have developed a rapid monitoring protocol for evaluating the success of many factors (i.e., hydrology, geomorphology, species diversity, plant survivorship, growth, etc…) for mangrove restoration projects in Southeast Asia.

2 BACKGROUND

Two approaches have been used for mangrove ecosystem restoration worldwide. The first approach that has been used extensively is the artificial regeneration or plantation approach. An approach that has been used more recently is the natural regeneration or the Ecological Mangrove Restoration (EMR) approach. Prior to 1982, the goals and objectives for most mangrove restoration projects focused on restoring the ecological goods and services of mangroves such as timber and fuel wood. Therefore, monoculture plantation was the primary approach for mangrove restoration before 1982. In 1982, restoration ecologist, Robin Lewis III, suggested that mangrove restoration projects should aim to restore ecosystem function rather than goods and services (Ellison 2000). Moreover, Lewis III founded a new technique for mangrove restoration that he called the Ecological Mangrove Restoration (EMR) approach that focused on correcting the hydrological features of the restoration site first, thereby creating a foundation to increase plant species diversity naturally (Lewis III 1999). Figure 3 illustrates a comparison of the number of species used in mangrove restoration projects between pre-1982 and post-1982 worldwide.

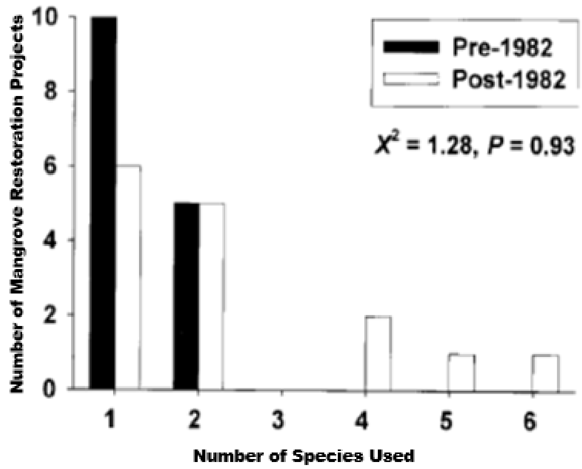


Figure 3. Species diversity of mangrove restoration projects pre- and post-1982 (Ellison 2000).

2.1 Plantation Approach

Artificial regeneration or the plantation approach uses hand planting of desired propagules and saplings at selected areas to restore mangrove forests. Monoculture plantations were the primary mangrove restoration approach prior to 1982, because it gave restorationists the ability to plant and harvest desirable mangrove species. Therefore, the outcome can either have a high or low species richness depending on the survivorship of planted species and the overall success of restoration but will always have low diversity (Ellison 2000). The areas planted are either mudflats thought to be suitable for mangrove ecosystems or former degraded mangrove ecosystems.

Field (1998) discussed the different techniques used in the mangrove plantation approach. One technique is to transplant seedlings from a mangrove forest to the restoration site. Another technique is to collect ripe seeds or propagules and directly plant them at the restoration site. Alternatively, desired seedlings or propagules may be raised under nursery conditions and then transplanted at the restoration site.

According to Kairo et al. (2001), there are several advantages of the plantation approach such as the ability to control species composition and distribution. However, there are also disadvantages of the plantation approach that might outweigh its advantages. The disadvantages of the plantation approach as mentioned by Kario (2001) are that it can be expensive especially in areas with modified hydrological regimes. Also, the plantation approach has not been perfected for many species. Not enough is known about the environmental requirements and tolerances of many mangrove species. Most mangrove ecosystem restoration projects that use the plantation approach often used familiar families like *Rhizophoraceae*, *Sonneratiaceae*, and *Avicinniaceae*. Often time species are planted in areas that they do not normally grow and they cannot tolerate the environmental conditions in the area planted. Moreover, the plantation approach often results in a long-term loss of ecological productivity by simplification of the ecosystem from mixed to monoculture plantations. Therefore, the biodiversity also decreases.

2.2 Ecological Mangrove Restoration (EMR) Approach

The Ecological Mangrove Restoration (EMR) approach was developed by restoration ecologist, Robin Lewis III. Since 1992, the Mangrove Action Project, a nonprofit organization dedicated to protect and restore mangrove ecosystems, has been implementing this restoration approach. The EMR method focuses on evaluating and creating the right hydrology in restoration sites first, which then allows for colonization of plants on their own in the best locations rather than just direct planting of individual mangrove species. Unless natural recolonization of soils in these areas fails, planting of mangrove species has been unnecessary in the EMR method. Typically the restoration of natural hydrology will introduce mangrove propagules through the tidal ebbs and flows. The advantages and disadvantages of EMR approach comparing to the plantation approach are shown in Table 2. Although it takes more time for mangrove species to recruit naturally at restoration sites, there is a higher species diversity and biomass over the long-term.

Table 2. The advantages and disadvantages of the EMR approach (Kairo et al. 2001).

Advantages:
– cheaper to establish,
– less subsidy is needed in terms of labour and machinery,
– less soil disturbance,
– saplings establish more vigorously,
– origin of seed sources usually known.
Disadvantages:
– replacement may not be of the same species removed,
– absence of mother trees may result in low/or no propagules supply,
– genetically improved stock not easily introduced,
– excessive wave action may cause poor establishment,
– predation of propagules by macrobenthos (e.g. crabs, snails etc),
– less control over spacing, initial stocking and composition of seedlings.

2.2.1 Six Steps for Successful EMR

Mangrove Action Project promotes a six-step approach for successful mangrove restoration called "Ecological Mangrove Restoration" or EMR (Quarto 2007). The purpose of this approach is to inform restoration planners that they cannot expect to meet mangrove restoration goals simply by planting mangroves alone without the application of the EMR principles. The six key steps to successful mangrove restoration is to work together with communities, organizations, and local governments to:

1) Understand the ecology of the naturally occurring mangrove species at the site such as the patterns of reproduction, distribution, and successful seedling establishment.
2) Understand the normal hydrology that controls the distribution and successful establishment and growth of targeted mangrove species.
3) Assess the modifications of the mangrove physical environment that occurred and that currently prevent natural secondary succession.
4) Select appropriate restoration sites through the application of steps 1-3 that are both likely to succeed in rehabilitating the mangrove forest ecosystem and are cost effective. Consider the available labor to carry out the projects, including adequate monitoring of

their progress towards meeting quantitative goals established prior to restoration. This step includes resolving land ownership and land use issues necessary for ensuring long-term access to, conservation, and sustainability of the site.

5) Design the restoration program at appropriate sites selected in step 4 to restore the appropriate hydrology and utilize “volunteer” mangrove recruitment for natural plant establishment.
6) Utilize active planting of propagules or seedlings only after determining (in steps 1-5) that natural recruitment will not provide the quantity of successfully established seedlings, rate of soil stabilization, or growth rate of saplings as required for project success.

In most cases, planting mangrove species at restoration sites is unnecessary. However, local communities plant propagules and/or seedlings even after having undertaken EMR for a combination of five reasons:

1) Impatience.
2) Intentional actions to provide measure of protection and ownership of restoration sites to show outsiders, people who are not aware of the project, that there is human activity in the area.
3) Promotion of growth of preferred species such as *Rhizophora* over early colonizers such as *Avicennia* or *Sonneratia.*
4) To encourage and ensure local community participation in restoration efforts, as direct involvement may inspire better stewardship and a keener sense of project ownership by local communities (Rönnbäck et al. 2007).
5) To earn income, as some NGOs and government agencies specially budget funds for planting mangroves regardless of actual need at given project sites.

3 METHODS

I evaluated mangrove ecosystem restoration projects by reviewing reports and journal articles describing completed restoration projects that used both the plantation and EMR approaches. Upon reviewing results from previous restoration projects, I found that monitoring data and proper documentation of restoration projects were nonexistent, inconsistently collected, or inaccurately reported. The lack of data made it difficult to accurately evaluate previous mangrove ecosystem restoration projects. In order to make evaluation of those projects and future projects possible, I have developed a monitoring protocol to be used for documenting success of every mangrove ecosystem restoration project. I developed this monitoring protocol by reviewing and incorporating portions of several mangrove monitoring manuals, including one from the Pacific Islands region developed by Ellison et al. (2012) as well as other ecosystem monitoring manual such as riparian vegetation monitoring protocol by Coffman (2012).

4 PLANNING FOR SUCCESSFUL MANGROVE RESTORATION

Effective planning is a critical step in ecosystem restoration. It is needed in order to ensure and maximize the overall success of restoration projects while also minimizing cost and avoiding repeated mistakes. Many restoration projects failed or have not reached their planned goals or objectives because the planning process has been too limited. However, Pastorok et al. (1997) have developed an ecological planning process for ecosystem restoration that is appropriate for mangrove restoration in Southeast Asia. The idea of the process is to integrate a fundamental understanding of ecological principles into the existing project planning framework used by the U.S. Army Corps of Engineers for their restoration projects.

4.1 Importance of Planning

The ability to identify key ecological processes within the ecosystem of interest and understanding those processes in relation to the objectives of the project are vital to successful planning process. Figure 4 illustrates the steps and components of the ecological planning process and their relationships among one another. Pastorok et al. (1997) have classified the five major element of the ecological planning process.

1) Defining goals and objectives
2) Ecological modeling and key parameters (include conceptual model)
3) Dealing with uncertainty
4) Restoration design, feasibility analysis, and experimentation
5) Implementation, monitoring, and adaptive management

4.1.1 Defining Goals and Objectives

Defining goals and objectives is one of the most important elements in the restoration planning process; it helps set expectations and determines the kind and extent of post-project monitoring. Therefore, it is the first step to take when planning for an ecosystem restoration project. It is also very important to have a full understanding of restoration site and its history in order to define objectives. Project objectives should be as specific as possible to maximize project effectiveness. For example, an objective for mangrove ecosystem restoration may be to increase percent survivorship of recruited species by 20% over the first 5 years. Both goals and objectives should be appropriate for the project. For mangrove ecosystem restoration projects, it is possible to restore some ecological functions when important parameters like soil type and site condition have been altered. However, if the goal of the restoration project is to return the restoration site to a fully functioning, undisturbed pristine predevelopment condition, then the likelihood of project failure is increased (Wetlands Reserve Program 2000).

Restoration planners should set goals and objectives that are achievable and justifiable rather than going over the limit to set goals and objectives that are impossible to achieve. Identifying and sampling reference sites may help to better define objectives. Reference sites are used to define the current status of the site, potentially achievable conditions for restored site, and as a reference point to evaluate project success (Clewell et al. 2005). Reference site should be located in the same plant zone, in close proximity with the restoration site, and should be exposed to similar natural disturbances or conditions. Restoration planners will have an idea of how they should set restoration project goals and objectives based on available data from reference sites. Although sampling reference sites will increase the cost of restoration projects, they are essential for evaluating restoration success.

4.1.2 Ecological Modeling and Key Parameters

A conceptual model of an ecosystem can be developed from the objectives of the restoration project and existing data from the restoration site. In addition, the conceptual model helps restoration planners understand the cause of the observed changes in a degraded ecosystem. Relationships among targeted species, performance indicators, and key ecological parameters are shown in a conceptual model. Therefore, conceptual models can be used to develop restoration hypothesis. Expected changes in performance indicators in relation to key ecological parameters are often stated by the restoration hypothesis. Key ecological parameters are the driving variables that limits community function and structure and influence performance indicator. Sometimes a variable can be both key parameter and performance indicator such as species abundance.

4.1.3 Dealing with Uncertainty

Uncertainty increases the risk of failure in restoration projects. Therefore, it is recommended that restoration planners are prepared to deal with uncertainty and failures. Perhaps it is the best strategy to maximize restoration project success. By characterizing uncertainty and variability during project planning, restoration planners will also have the ability to predict ecosystem development, potential success, and potential failure of the project. Dealing with uncertainty will also help restoration planners to better understand the cause of failure.

4.1.4 Restoration Design, Feasibility Analysis, and Experimentation

Restoration design can be developed from conceptual models as well as from data collected from previous restoration projects. Confidence in a restoration design will generally be higher if restoration planners have more data from previous restoration experiments and case studies. Moreover, experimental designs may be conducted in order to determine the cost effectiveness and feasibility of a restoration project. Experimentations also provides information on how a restoration project will impact the ecosystem, identifying both positive and negative effects. Therefore, potential risks of a project can be avoided using experimentation.

4.1.5 Implementation, Monitoring, and Adaptive Management

Monitoring is another critical part of the whole project, because it determines and evaluates the effectiveness and success of restoration projects. Without monitoring data, restoration planners will never know if the restoration project was a success or failure. If the outcome of the restoration project does not turn out as planned due to uncertainty and variability, restoration planners will have to come up with adaptive management plan if they want to make sure a project is successful.

According to Pastorok et al. (1997), the key purpose of monitoring with respect to adaptive management is twofold. First, monitoring gives guidelines to further manipulate restoration projects that will improve the outcome in relation to prior project objectives. Second, monitoring allows restoration planners to evaluate the effectiveness of a specific restoration approach or technique. However, the monitoring process is currently neglected in most restoration projects which leads to the incapability of evaluating the true effectiveness and success of a particular restoration project.

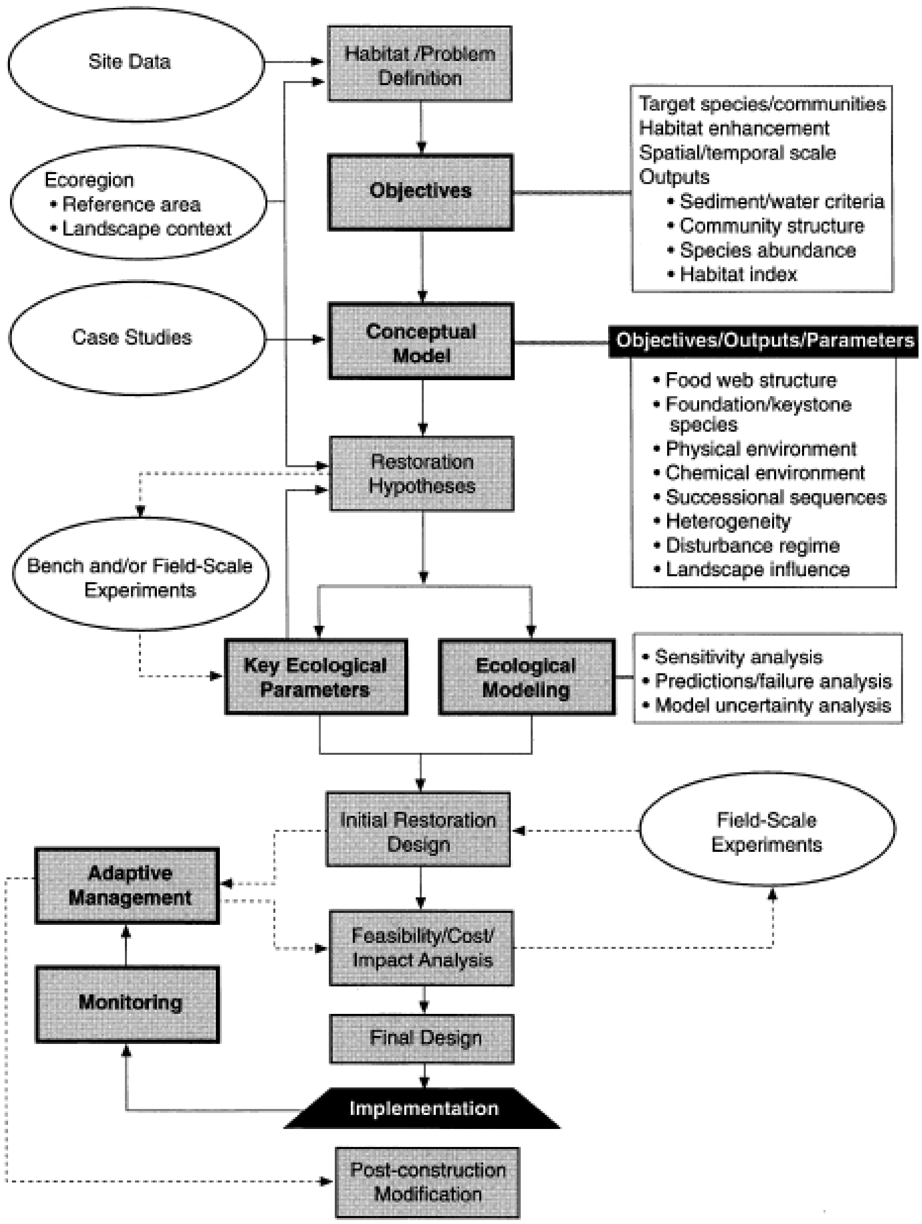


Figure 4. Ecological planning process for ecosystem restoration projects (Pastorok et al. 1997).

4.2 Important Factors Affecting Successful Mangrove Restoration

It is widely noted that mangrove forests are one of the most threatened tropical ecosystem. Valiela et al. (2001) reported that at least 35 percent of mangrove ecosystems have been lost in the past two decades. Most of the time, mangrove ecosystem are irreversibly destroyed but they can also be restored in some cases. In rare cases, even new areas can be claimed for mangrove growth which also increase mangrove ecosystem restoration efforts (Elster 1999). However, when planning for mangrove restoration, several factors have to be carefully considered in order to implement a successful mangrove ecosystem restoration.

4.2.1 Hydrologic Regime

Many mangrove restoration projects failed due to a lack of understanding of mangrove hydrology. Hydrologic regime is one of the most important factors that influence mangrove ecosystem restoration success. The survivorship, growth rate, and distribution of mangrove species are controlled by the hydrologic patterns in a restoration site. Moreover, hydrology of the site also controls the quantity, quality, and timing of water entering the site. Therefore, it is critical that restoration planners determine the normal hydrologic pattern such as depth, duration and frequency of tidal inundation, and tidal flooding of the restoration site (Kairo et al. 2001; Quarto 2007). In addition to hydrology, geomorphology of the restoration site is another important factor affecting restoration project success. For example, gentle slope is needed for proper drainage. According to a report by Mangrove Action Project (MAP) (2007), different mangrove species thrive at different inundation or water levels. Some thrive in deep water, while some prefer shallow water. For example, if one species is dominant in one location that does not mean that it will be dominant in another location with different hydrological conditions. Therefore, it is crucial to know the critical periods of dryness and inundation at the restoration site in order to determine the zonation of each species. The best approach to identify mangrove zonation is developed by Watson (1928) based on the degree and tidal inundation of a reference site he worked on in Malaysia. Table 3 shows the inundation classification of some of the most common mangrove species in Southeast Asia. The classes are subcategories of mangrove zonation.

Table 3. Inundation classification of mangrove species in Southeast Asia (Watson 1928).

Class	Flooded By	Height above chart datum in feet (meters)	Flooding Frequency (times/month)
1	All high tides	0-8 (2.44)	56-62
2	Medium high tides	8-11 (3.35)	45-59
3	Normal high tides	11-13 (3.96)	20-45
4	Spring high tides	13-15 (4.57)	2-20
5	Abnormal (equinoctial tides*)	15	2

**Equinotical tides are extremely high or low tides which occur twice a year around March 21 and September 23.*

MAP (2007) provided an explanation of how to apply class 1-5 of inundation as follows:

Class 1:

Mangroves in class 1 are inundated by all high tides. The dominant species found in this type of environment are *Rhizophora mucronata*, *Rhizophora stylosa*, and *Rhizophora apiculata*.

Class 2:

Mangroves in class 2 are inundated by all medium-high tides. The dominant species found in this type of environment are *Avicennia alba*, *Avicennia marina*, *Sonneratia alba*, and *Rhizophora mucronata.*

Class 3:

Mangroves in class 3 are inundated by normal high tides. Most species thrive under these conditions. This class of mangrove ecosystem has the highest biodiversity because most species falls into this class. Common species include: *Rhizophora* spp., *Ceriops tagal*, *Xylocarpus granatum*, *Lumnitzera littorea*, and *Exoecaria agallocha*.

Class 4:

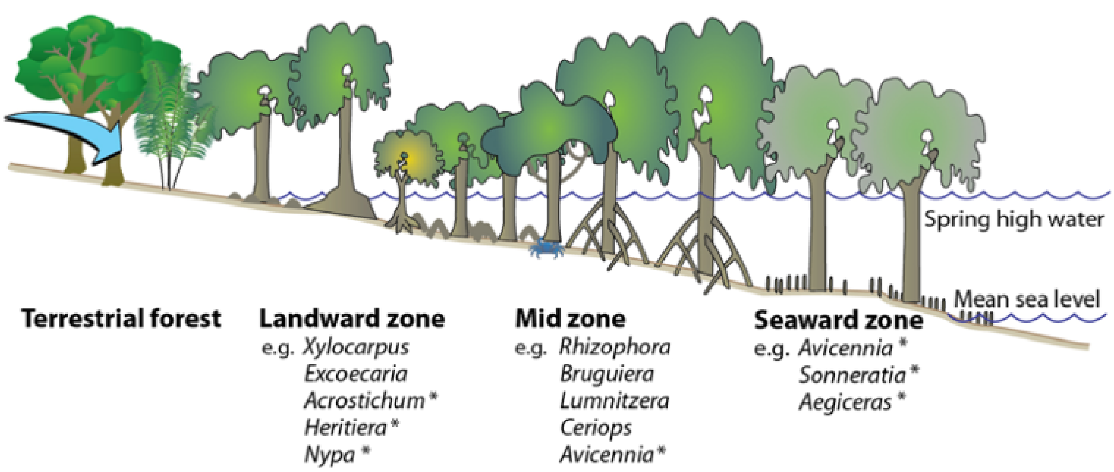
Mangroves in class 4 are inundated only during spring tides. Common species include *Bruguiera* spp., *Xylocarpus* spp., *Lunitzera littorea*, and *Exoecaria agallocha*. This type of environment is generally too dry for *Rhizophora* spp., but they may occur in low abundance.

Class 5:

Mangroves in class 5 are inundated only during equinoctial or other exceptional high tides. Dominant species are *Brugeira gymnorrhiza*, *Instia bijuga*, *Nypa fruticans*, *Herritera littoralis*, *Exoecaria agallocha*, and *Aegiceras* spp.

4.2.2 Zonation

Every mangrove species has its own level of salinity tolerance. Therefore, mangrove zonation varies from place to place. Mangrove zonation is a result of environmental tolerance and physiological preferences of individual mangrove species (Kairo et al. 2001). Moreover, mangrove zonation is classified into three zones according to where they occur in relation to tidal position consisting of seaward, mid, and landward zone (Waycott et al. 2011). The seaward zone is the edge of the mangrove ecosystem next to the open water (tidal channel, slough, estuary or ocean) which is fully exposed to all tides and frequent inundation (inundation class 1-3). The soil conditions in the seaward zone are generally soft mud and sedimentary in origin. One of the distinctive characteristics of mangrove species in this zone is having aerial roots that anchor and supports the plant. On the other hand, the mid zone is subject to less regular tidal influences where the mangrove inhabitants are exposed to inundation only during the spring high tides (inundation class 4). The soil condition in this zone is similar to the seaward zone. However, the soil in the mid zone is more compact than those of the seaward zone. The third zone, landward, faces inundation only during the highest of spring tides (inundation class 4-5) and receives freshwater from groundwater or land surface runoff. The landward zone is usually a narrow strip of vegetation that may transition to a terrestrial forest. Figure 5 illustrates different species of mangroves in different zones.



** Occurs in the western Pacific only*

Figure 5. Typical mangrove zonation of all mangrove ecosystem (Waycott et al. 2011).

4.2.3 Soil and Substrates

Mangroves grow in different combinations of sand, silt, and clay which often contain a high concentration of organic matter. The different soil types can influence the distribution of mangrove species. However, mangrove ecosystems grows best on low energy muddy shorelines where there is an extensive suitable intertidal zone with abundant supply of fine grain sediment (Field 2007). Soils that are stable, non-eroding, and have a sufficient depth are ideal to support plant growth. Another typical feature of soil in mangrove ecosystems is the development of iron pyrite (FeS_2). Iron pyrite developed from the presence of iron, sulfate, organic matter, and the lack of oxygen in freshwater before mixing with seawater. Chemical reactions under these conditions lead to the formation of potential acid sulfate soils. Potential acid sulfate soils are highly acidic and may be problematic for some mangrove species to grow (Giesen et al. 2006). Moreover, the rate of sedimentation is another important factor, because some amount of sedimentation is needed on site to help stabilize the seedlings. However, too much sedimentation may stifle all plant growth in the ecosystem. On the other hand, sediment erosion is not good for the restoration site because it weakens the root structures and increase the duration of inundation.

4.2.4 Salinity

Mangrove ecosystems are composed of halophytic plants (vegetation) that grow in high salinity water. Mangrove species have adaptations that allow them to tolerant high levels of salinity. Salinity is an important factor in reducing competition between mangrove species and other vascular plants. However, mangrove species also need freshwater for their germination, growth and survivorship. Due to the fact that mangroves are halophytes, it might seem strange that these species required freshwater, but some mangrove species even grow well in only slightly brackish conditions. On the other hand, hypersaline conditions can threaten all mangroves species, as it creates the same problem that terrestrial plants face during drought. Although some species will survive under the conditions of hypersalinity, none of the mangrove species can grow optimally under these conditions. Therefore, the right salinity level can be advantageous for mangrove species, but it can also have adverse effects on mangrove species under the conditions of hypersalinity. Restoration planners need to take into consideration of the dominant mangrove species in the restoration site and determine the optimum salinity levels or thresholds for those plants (Field 1998; Waycott et al. 2011).

4.2.5 Tidal Fluctuation and Wave Energy

Although tidal influence is not a direct requirement for mangrove ecosystems, it plays an important indirect role. Namely, tidal fluctuation in combination with salinity creates an ecosystem that is only suitable for mangrove species. Thus, excluding other vascular plant species and reducing competition. Tides also bring salt water up the estuary against the outward flow of freshwater, allowing mangrove species to become well established inland. Moreover, tides are capable of transporting nutrients into mangrove ecosystem as well as exporting organic carbon and reduced sulfur compounds (Odum 1982). Tidal fluctuations are very important in areas where there are high rate of evaporation because they help prevent the conditions of hypersalinity in soil which is detrimental to mangrove species. Lastly, the dispersal of mangrove seedlings and propagules are aided by tidal action.

In terms of wave energy, mangrove species grow best in depositional environments with low wave energy. High tides are not ideal in a mangrove ecosystem because they prevents mangrove propagule and seedling establishment. High wave energy also destroys the shallow mangrove root system and prevents the accumulation of fine-grained soil composed of silt, clay, and high content of organic matter.

4.2.6 Propagule Availability and Nursery Technique

Mangrove species are capable of regenerating naturally given suitable conditions for growth and establishment. Mangrove seedlings and propagules can be transported into the site when natural hydrology of restoration sites is restored. However, planting of mangrove species might be necessary if natural recolonization of mangrove species does not occur. Therefore, it is very important to know the appropriate nursery techniques. The establishment of a mangrove nursery has been found to increase the survival of nursery seedlings up to 90% (Ravishankar and Ramasubramanian 2004). Bovell (2011) identified the necessary steps for nursery technique into the following:

1) Selecting a Suitable Nursery Site

The first step to be done in mangrove nursery is to select a suitable site. The mangrove nursery site should be selected in the intertidal zone in close proximity to creeks with appropriate drainage. Moreover, water quality of the site has to be good and the site needs to be fenced in order to avoid potential propagule predation.

2) Nursery Bags

5 in. x 8 in. polythene bags should be used to raise mangrove seedlings in the nursery. This will give the root enough space and stay healthy even after 2-3 months of growth in the nursery bags.

3) Preparing Soil for Containers

Only clayey wetland soil should be used for preparing the containers because most mangrove species grow well under these soil conditions. The clayey soil can be collected during low tides in the mudflats. Hard materials and other debris should be removed before filling the nursery bags with the soil.

4) Seedlings and Propagules Collection and Management

Mangrove species should be selected based on the salinity in relation to the restoration site. Mangrove seedlings and propagules are sensitive living plants; therefore, they must be carefully collected, cleaned, and protected to keep them alive and healthy. Collecting seeds from healthy, mature trees is also very important; the more mature the tree the better quality seeds it produces. Lastly, collected seeds should be planted within 48 hours of collection to avoid difficulty in seed germination.

4.2.7 Ecological Knowledge and Community Participation

Rönnbäck (2007) reported that the attitudes towards mangrove restoration projects of local communities are based on how much ecological knowledge they have of mangrove ecosystems. People who have ecological knowledge of mangrove ecosystem will have positive attitude towards restoration projects compared to people with low or without ecological knowledge of mangrove ecosystems. Stone et al. (2008) suggested that community involvement may be a key factor in increasing the potential for successful mangrove ecosystem restoration for two main reasons. First, most agencies often have limited budget for the whole restoration project. Therefore, having local community assistance with planting will help these agencies in leveraging their budgets with the community contributions of cash, labor, physical resources, and management inputs. Another reason is that any restoration efforts against the community's wish will usually result in a potential backlash and a unsuccessful program. Moreover, knowing the reason that motivates local communities to participate in a restoration project is very useful and will help managers in designing education, promoting community participation, and making funding decisions in the future.

4.2.8 Monitoring

Once a mangrove ecosystem restoration project has been completed, it is essential to monitor progress, maintain the site, and evaluate the success of the project. Although monitoring is one of the final steps in restoration, it is one of the most important processes of restoration. There are four main reasons for monitoring: evaluation of project effectiveness, maintenance, adaptive management, and enhancement of science and management understandings (NOAA Restoration Center and NOAA Coastal Services Center 2010). Without monitoring data, it is impossible to determine the effectiveness and the success of restoration projects. Field (1998) suggested that the monitoring period of mangrove restoration projects should take at least three to five years for small-scale projects but realistically ten years. On the other hand, the monitoring period for large-scale projects should be up to 30 years. Moreover, monitoring indicates maintenance needs such as invasive species control, debris removal, signage maintenance, and fence maintenance. Careful monitoring will allow project practitioners to observe the project carefully and applied adaptive management whenever it is needed. According to (U.S. Department of the Interior 2010), adaptive management is a systematic approach for improving resource management by learning from management outcomes Some of the common corrections in the middle of restoration projects are channel modifications, hydrology corrections, and replanting or re-seedling of vegetation. In addition, monitoring data from current restoration projects will improve the understanding of mangrove ecosystems for future restoration projects as well as increase the potential for project success.

Holl and Cairins (2002) categorized monitoring as three types of activities. The first activity is the act of sampling/surveying, which is gathering data at a specific point in time. The second monitoring activity is surveillance, a systematic and orderly gathering of specific data over a period of time. Finally, the third category of monitoring is monitoring itself or the process of surveillance undertaken to ensure that the goals and objectives of the restoration project are being met. Therefore, it is important to examine the definition of monitoring to avoid collecting endless data that are never used to evaluate the success of a restoration project.

First, the goals and objectives of restoration projects need to be clearly defined because different goals and objectives require monitoring of different parameters to evaluate success. Second, specific monitoring protocols must be outlined during the planning process, not after the implementation of the restoration project. Unfortunately, many restoration projects tend to determine the need for monitoring after the project has been implemented. As a result, monitoring protocols might not be designed appropriately and sometimes monitoring will be neglected, leading to a lack of data in most cases. Moreover, restoration projects are being viewed as final products rather than an ongoing process in most cases. If restoration planners viewed restoration as a final product, they may conclude that the project is successful after restoration is completed without monitoring. However, restoration is an ongoing process that requires a monitoring process in order to determine whether the project was successful or not (Ambrose et al. 2007). Finally, monitoring will help restoration planners and managers determine the factors influencing the success or failure of a particular restoration project. The challenges of successful monitoring are being able to have an effective and specific design as well as a commitment to implementation of the monitoring process. Elzinga et al. (1998) identified several important points to consider during the monitoring process:

1) What are the parameters of interest?
2) What is an appropriate sampling size?
3) How sampling units should be positioned?
4) Should sampling units be permanent or temporary?
5) How many sampling units should be sampled?
6) How will data be presented?

Monitoring strategies and programs can vary depending on the type of ecosystems. In this research, I will only discuss the monitoring process for mangroves ecosystem which falls into the wetland category. Developing monitoring protocols for wetland ecosystems is one of the most challenging to establish. Wetlands are transitional between aquatic and terrestrial systems. Some of the common parameters monitored in wetland ecosystem are diversity, vegetation structure, and ecological processes (Ruiz-jaen and Aide 2005; Wortley et al. 2013). Species diversity is usually measured by determining the richness and abundance of organisms within different trophic levels. Whereas vegetation structure is often determined by measuring vegetation cover, woody plant density, biomass, or growth form. These measures are useful for predicting the trends of plant succession in an ecosystem. Ecological processes such as nutrient cycling and biological interactions are also important to measure because they provide information on the resilience of a restored ecosystem.

5 PLANTATION ATTEMPTS

The widespread loss and degradation of mangrove ecosystems have caused an increase in awareness and number of restoration efforts throughout the world. The plantation approach is one of the primary approaches that is used worldwide for mangrove ecosystem restoration. The plantation approach can establish a new mangrove ecosystem through afforestation on intertidal flats and other areas where they would not normally grow. The plantation approach can also be used at a former mangrove forest. There have been a number of documented mangrove restoration project successes and failures using the plantation approach (Erftemeijer and Lewis III 1999).

In Hong Kong, *Kandelia candel* mangroves were replanted in an intertidal mudflat area of 1,000 m^2 as a mitigation project to compensate from the damage from coastal construction activities. The entire project cost approximately HK$ 1,000 and took place from 1990-1991. The survival rate of the project was reported as “high”. However, there are no available data to support this statement.

In Ha Tinh Province of Vietnam, a mudflat area of 580 ha was planted with mangrove species *Kandelia candel* from 1989-1993. The project was funded by various NGOs with coastal protection as the main goal for the project. Survival rates were reported to be around 40%; however, more detailed data are still lacking.

Sanyal (1998) documented a mangrove restoration failure in West Bangal, India using the plantation approach. The project was implemented as part of the coastal zone management from 1989-1995. The objective of the restoration project was to artificially plant up to 9,050 ha of mangroves in barren reclaimed land. The success rate of the project was reported to be as low as 1.52%. However, it is unclear how they determine this success rate such as mangrove cover, density, or survivorship (Lewis III 2000).

In North Sulawesi, Indonesia, mangrove species have been planted on an abandoned shrimp pond five times over the period of eight years. Mangrove seedlings were planted without regard to ecological requirements that affect the effectiveness of the restoration project. Examples of ecological requirements are hydrology, inundation, salinity levels, and zonation. As a result of neglecting the ecological requirements, mangrove seedlings died within a year after each planting.

Several failures of the plantation approach have been documented in the Philippines. One example was the Central Visayas Regional Project-1. Mangrove species were planted in an area of 1,000 ha that was largely composed of mudflats and some degraded mangrove areas. This US$ 3.5 million project was funded by the World Bank and took place from 1984-1992. Monitoring data was taken from 1995-1996 and the data collected indicated that only 18.4% of the planted mangrove species in 492 ha survived (Lewis III 2005).

In 2006, two mangrove restoration projects were implemented in the Philippines which were sponsored by the PEW Grant for Mangrove Conservation. The two projects are still active as of today. The first project was conducted along the Iloilo River where 400 seedlings of *Avicennia marina* were planted along the riverbank. The survivorship of the seedlings was approximately 50% after six months, but dropped to <10% after 1.5 years after project implementation (Samson and Rollon 2008). Frequent flooding and inundation was the main contributor to this high mortality rate, other factors included anthropogenic activities such as water pollution, digging up of substrate, and trampling by fishermen.

The second restoration project was conducted in 5 ha of coastline in the Dumangas municipality. Approximately 20,000 mangrove seedlings that were planted in Ermita, Dumangas died within 3 months of the plantation. Species composition included: 90% *Avicennia marina* and 10% *Sonneratia alba* and *Rhizophora* spp. One of the factors that affected mortality was the location of the plantation. The seedlings were planted in the lower intertidal to subtidal flats with seagrass patches. Therefore, the seedlings suffered from inundation as evidenced by rotting stems. Figure 6 shows the timeline of the planted mangrove species in Ermita, Dumangas.

Figure 6. Mangrove species planted in Ermita, Dumangas in 2006. **A.** Healthy *Avicennia marina* after 3 weeks. **B.** Dead after 3 months of planting. **C.** Rotting stems due to frequent inundation. **D.** Problems with algae and sediments. **E.** Planting was in the subtidal zone with visible seagrass beds. F. Problems with barnacles (Primavera and Esteban 2008).

Many mangrove ecosystem restoration projects using the plantation approach have also been documented in Thailand. Some documented projects succeeded as well as some failed. In 1990, an experimental mangrove plantation was planted on mudflats in Pattani Bay, Thailand. After three years of project implementation, a study showed high mortality rate for seedlings of *Excocercaria agallocha* and *Bruguiera cylindrical* (survival ranging from 5-18%). *eriops tagal* and *Rhizophora* spp. seedlings showed 30-34% survival and *Avicennia marina* seedlings showed 56% survival three years after project implementation. Another afforestation project in Samut Songkram, Thailand was implemented in an 800 ha mudflat area. The planted mangrove species were *Rhizophora mucronata* and *Aegialites rotunddifolia*. However, the survival rates for the planted species were low, especially for *Rhizophora mucronata*. The high mortality rate was due to damages caused by push-net boats, propagule predation by crabs, infestations of barnacles settling on the seedlings, and poor choice of mangrove species planted on mudflats.

A large increase in mangrove restoration efforts was due to the aftermath of the 2004 Indian Ocean Tsunami where it was proven by Kamthonkiat et al. (2011) that mangroves provide coastal protection against tsunami. A mangrove restoration project in Phang Nga, Thailand was implemented in 2005 to help mitigate the effects of the tsunami. However, the mangrove area in 2006 gradually decreased after the implementation of the restoration project by 7-8% compared to the reference year of 2003 where the total mangrove area was 20,678 ha (Figure 7). The restoration project was considered unsuccessful based on the growth rate, number of surviving trees, and recovery that was less than average as well as gradually decreasing mangrove areas (Kamthonkiat et al. 2011).

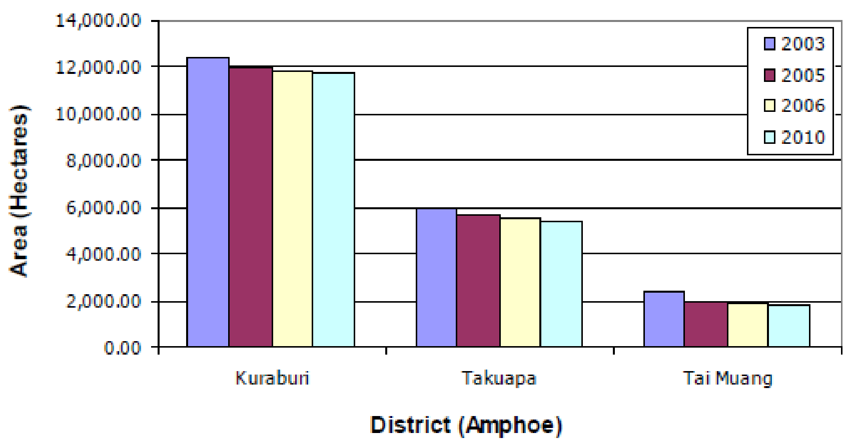


Figure 7. Changes in mangrove area in three districts of Phang Nga, Thailand (Kamthonkiat et al. 2011).

6 EMR ATTEMPTS

The other common mangrove ecosystem restoration approach is called Ecological Mangrove Restoration (EMR). EMR approach focuses on correcting the hydrology of restoration sites so that mangrove seedlings and propagules can recolonize naturally. Although not as many EMR projects have been documented compared to the plantation approach, there are still some documented projects. One of the earliest documented EMR implementation was carried out in the 1950s. This restoration effort started in order to restore mangrove areas affected by impoundments of the central east coast of Florida (Lewis III and Gilmore 2007). Fish data from pre- and post-impoundment of the restoration site showed that hydrologic restoration restored resident, transient and omnivore fish communities (Table 4). Moreover, invertebrate and plant communities were also restored by the EMR approach in this restoration project through reintroduction of tidal connection to the mangrove area restored. Therefore, the restoration project was considered successful due to the increased abundance of fish.

Table 4. Comparison of fish abundance before and after EMR in the central east coast of Florida (Lewis III and Gilmore 2007).

	Pre-impound. Harrington and Harrington, 1961		Post-impound. Harrington and Harrington, 1982		Restored Gilmore et al., 1985	
	No. Individuals	%	No. Individuals	%	No. Individuals	%
Mangrove resident species						
Omnivores grazing on detritus, algae, cyanobacteria, micro and macro invertebrates						
Cyprinodon variegatus	1,986	40.0	235	25	258,597	41.0
Poecilia latipinna	1,215	25.0	400	43	160,317	26.0
Gambusia holbrooki	1,769	36.0	300	32	210,080	33.0
Total residents	4,970	76.0	935	100	628,994	94.0
Mangrove transient species						
Top predators feeding on fish and macro invertebrates						
Centropomus undecimalis	172	38.0	0	0.0	4,005	53.0
Elops saurus	33	7.0	0	0.0	8,849	44.0
Megalops atlanticus	254	55.0	0	0.0	316	2.0
Lutjanus griseus	0	0.0	0	0.0	34	0.8
Total transient predators	459	7.0	0		13,204	2.0
Omnivores grazing on detritus, algae, cyanobacteria as well as micro and macro invertebrates						
Mugil cephalus	1,124	100.0	0	0.0	17,856	74.1
Mugil curema	0	0.0	0	0.0	3,064	10.7
Brevoortia smithi	0	0.0	0	0.0	78	5.4
Diapterus auratus	0	0.0	0	0.0	102	5.6
Archosargus probatocephalus	0	0.0	0	0.0	15	0.6
Gerres cinereus	0	0.0	0	0.0	328	0.4
Total transient omnivores	1,124	17.0			21,443	3.0
Total fish	6,553		900		670,194	

Another EMR attempt was conducted in Cross Bayou, Pinellas County, Florida in 1999. This restoration project was part of a negotiated settlement following the oil spill in Tampa Bay in 1993. The area of the restoration site was 1.9 ha along the Gulf of Mexico coastline near St. Petersburg where other mangrove areas were successfully reproducing (Lewis III et al. 2005). Therefore, restoration planners of the project expected natural regeneration to occur because of the abundant seedlings in the area. As a result, they did not perform any planting which saved approximately $24,000/ha in restoration costs. The hydrology and topography of the restoration site were corrected to provide suitable conditions for recolonization of mangrove seedlings. The result of the project was satisfying and considered as successful because the success criteria were met within three years of restoration. Mangrove cover was 3.7% after the first three months then increased to 94.7% after five years of project implementation (Figure 8).

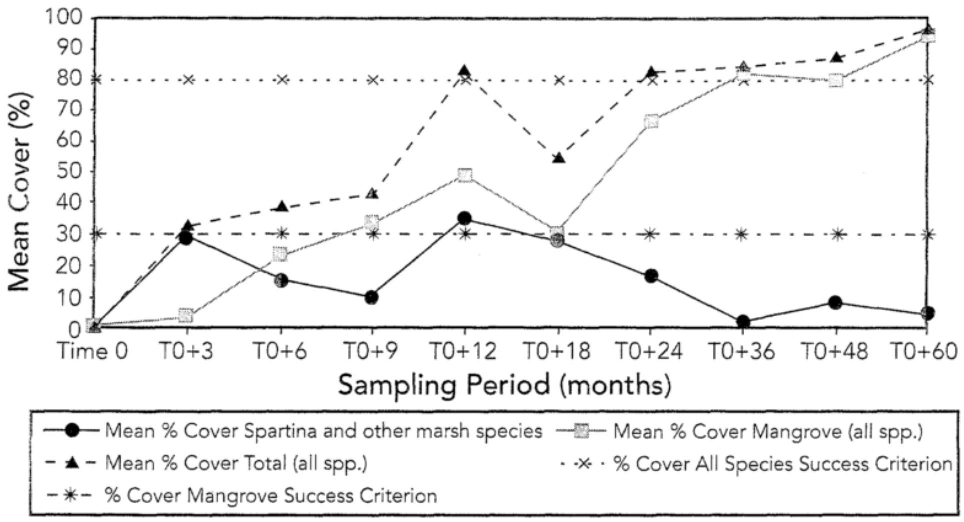


Figure 8. Mangrove cover increased from 3.7% to 94.7% within five year of project implementation (Lewis III et al. 2005).

One of the most successful mangrove ecosystem restoration projects using the EMR approach to date was the restoration of 500 ha area of mangrove restoration in West Lake Park, Hollywood, Florida. The restoration project started in 1989 and ended in 1996. The goal was to restore mangrove forest using a reference site as the model, which was the adjacent undisturbed forest. In order to recreate a site similar to the reference site, tidal creeks and shallow mudflats were added and the slope grade was adjusted from +27 cm to +42 cm mean seal level (MSL) (Lewis 2011). As a result of correcting the hydrology and geomorphology of the restoration site, no planting of mangrove species was necessary. All mangrove species naturally regenerated at the restoration site or what Lewis III (2009) called “volunteer” mangroves – mangrove seedlings and propagules that colonized the site on their own after appropriate biophysical conditions were established. Some common mangrove species that volunteered at the restoration site are *Rhizophora mangle*, *Avicennia germinans*, and *Laguncularia racemosa*. Figure 9 shows the photo documentation of the West Lake EMR project from 1989-1996.

Figure 9. Time sequence over 78 months of EMR project in West Lake, Florida. **A.** Time zero taken in July 1989. **B.** Time zero + 28 months taken in November 1991. **C.** Time zero + 78 months taken in January 1996 (Lewis III 2011).

Another EMR attempt was conducted in Puerto Rico. Mangrove species in more than 100 ha of mangrove areas of Laguna Boca Quebrada, Vieques were killed due to an alteration of hydrology in 1985. However, the area was vegetated in 1991 after the hydrologic regime was restored by removing a roadway (causeway) that consisted of fill material across the historic tidal connection to the ocean (Turner and Lewis III 1997). However, there are no data available to support the success of this project and what parameters were measured to determine success.

7 MAIN FINDINGS

The aerial extent of mangrove ecosystems has declined by 50 percent in the last century mainly due to mangrove land conversion to aquaculture, agriculture, and urbanized areas. This decline in mangrove ecosystems has led to a concern about the loss of ecosystem services, resulting in an increase in mangrove ecosystem restoration efforts worldwide. During the last 10 years, ecological restoration has been strongly advocated as a measure to offset ecological damage from urban development as mitigation (Twilley et al. 1999). Mangrove restoration projects aim to increase extent of mangrove forests and return these areas into functioning ecosystems again. Two primary approaches for mangrove ecosystem restoration have been used as discussed in Sections 5 and 6, namely the plantation approach and the ecological mangrove restoration (EMR) approach. The initial goal of my research was to compare the two mangrove ecosystem restoration approaches. However, there was insufficient documentation of previous mangrove ecosystem restoration projects, a lack of restoration site understandings, and a lack of monitoring data. These factors made it difficult to compare the two mangrove ecosystem restoration approaches to determine and evaluate which approach was a more effective mangrove ecosystem restoration approach.

7.1 Lack of Site Understanding

Mangrove ecosystems can self-repair successfully within 15-30 years, given the right hydrology and availability of mangrove species waterborne seedlings (Wetlands Reserve Program 2000). If the hydrology is right but natural recolonization does not occur, mangrove ecosystems can then be established by active planting. However, many mangrove ecosystem projects move immediately to the planting process without determining why natural recovery has not occurred. One of the reasons that natural recovery does not occur can be due to a blocked tidal flow that prevents mangrove seedlings and propagule from recolonizing. The most common cause of restoration project failure is from planting of inappropriate mangrove species in locations that do not have suitable conditions for mangrove species to thrive. In general, these causes of failure resulted from a lack of understanding of the physical environment of the restoration site and species requirements or tolerance limits. Mangrove Action Project (2013) highlighted the important questions that are often overlooked in the planning process of a mangrove ecosystem restoration projects below:

1) What is the history of the restoration site?
2) What mangrove species grow there historically before it was impacted?
3) Which zone did each species grow?
4) What caused the destruction or degradation of the mangroves?
5) What are each species hydrological requirements?
6) Where were the freshwater inputs into the area?
7) Where did exchange of tidal and seawater take place?

7.2 Lack of Documentation

Although many mangrove restoration projects have been implemented around the world, only a small amount of these projects have been planned or studied by scientists. As a result, there is often a lack of documentation of project evaluation especially when the project fails (Kamili and Hashim 2008). It is very important to document each restoration project regardless of success or failure. Without sufficient information on previous restoration efforts, it is difficult to review and determine the reasons for success or failure of most restoration projects. However, it is believed that the lack of using an ecological planning process and setting realistic goals are the main reasons why most restoration projects fail.

7.3 Lack of Monitoring Data

I have found that there are insufficient monitoring data available to compare and evaluate the two mangrove ecosystem restoration approaches. This makes it scientifically impossible to determine which approach is a more effective restoration approach. Although there are many mangrove ecosystem restoration projects that have been reported as successful, there were insufficient data to support how the project was evaluated as successful. For example, in the mangrove restoration project in Hong Kong that took place from 1990-1991, the survival rate of replanted mangrove species for the project was reported as “high” and the project was considered a success. However, there are no data to support this reported statement. Because the project length was only a year, the reported “high” survival rate is misleading. The monitoring period would need to be at least 3-5 years after project implementation in order to determine the initial progress of the overall restoration project. Moreover, I found projects that neglected the entire monitoring process all together. This challenges the whole restoration project because success cannot be evaluated. There are several reasons why it is important to monitor a restoration site after project implementation:

1) To record the progress of restoration.
2) To quantify the recruitment, establishment, and early growth rate of mangrove species in an initial period after restoration (usually 3-5 years).
3) To identify early issues with mangrove species establishment and use adaptive management strategies to rectify the problem.
4) To increase community participation, knowledge, and understanding of the entire process of restoration.
5) To inform future management strategies in the restored mangrove ecosystem.
6) To provide helpful data for future mangrove ecosystem restoration projects.
7) To evaluate the success of a restoration project.

8 MANAGEMENT RECOMENDATIONS

8.1 Development of a Monitoring Protocol for Southeast Asia

Although I have been told and have read that EMR is a better alternative for mangrove ecosystem restoration, I cannot make this conclusion due to the lack of monitoring data available to compare and evaluate the two restoration approaches. Therefore, I developed a monitoring protocol that I recommend be incorporated in the final stage of a restoration project.

The objective of developing this monitoring protocol was to evaluate the restoration of mangrove ecosystems consistently throughout Southeast Asia. Some of the common parameters that will be monitored include planting survivorship, vegetation structure, species diversity, and sedimetation. This monitoring protocol was adaptated from internationally accepted monitoring methods appropriate for Southeast Asia, with three levels of intensity of monitoring (Coffman 2012; Ellison 2012). In addition, a photo monitoring was incorporated into the protocol to monitor the overall visual change of the restoration site over the monitoring period (Shaff et al. 2007).

Level 1:

Transect based survey recording mangrove locations, species, mangrove conditions, and identifying stressors. Level 1 is quick to do and is a suitable for capacity building with community groups.

Level 2:

Vegetation plots in each zone recording community structure, species diversity, height, diameter of tress, and density of seedlings. Level 2 takes about one day per transect and is better carried out by project staff with the help of community involvement.

Level 3:

We recommend monitoring sedimentation in level 3, although other factors may be monitored depending on the project objectives. This level takes the greatest amount of time but can produce the most detailed information on sedimentation trends.

Photo Monitoring:

Photo point monitoring is a process of taking repeated photographs of the restoration site over a period of time at the same location. Photo monitoring is an easy yet effective monitoring method to observe the overall ecosystem change over time.

8.1.1 Level 1: Transect Based Survey

Level 1 monitoring documents what mangroves are currently present and the conditions of the baseline mangrove restoration site. In this protocol, I propose an interrupted line transect method. This technique surveys the mangrove species that are present along the transect line in the various zones at every meter mark or random points along the transect. It is recommended that Level 1 monitoring be carried out every three months (four times a year).

8.1.1.1 Planning and Preparation for Fieldwork

1) Conduct fieldwork during low tide period.
2) Determine the extent of the restoration site by using the most recent aerial photo available.
3) Examine the aerial photo obtained or use Google Earth to identify the approximate extent of mangrove zones present, disturbances, and changes of mangrove forest over time.
4) Photocopy the aerial photograph, preferably colored copy. Mark the vegetation zones on the photo and also include a scale and the North arrow. This will be the copy that you will take into the field to accurately check the types and positions of the zones.
5) Draw a line on the copy of the aerial photo to determine the location of the transect. It is recommended to establish at least three transects in each restoration site and a transect should start from upland to the open water (landward to seaward zone, Figure 5). All transects should be placed perpendicular to the waterline.
6) Mark any prominent landmarks or geomorphic features on the copy of the aerial photo to help you identify the location of transect lines once you are in the field.
7) Assign monitoring team. Never perform fieldwork alone. Always work in a group of two or three for safety and to get representative averages for monitoring data.
8) Make sure you have all the field equipment needed before heading to the field (see Table 5 for an equipment checklist).

Table 5. Equipment checklist for fieldwork.

EQUIPMENT CHECKLIST	
Pencils	Photocopy of the aerial photo of the site
Copies of data sheets	GPS
Clip board	Ziplock bags for plant collection
Measuring stick / Telescoping measuring rod	Tape measures (2)
100 m fiberglass transect survey tapes (3)	Flagging stakes
Flagging tape	Hammer
Numbered tags	Steel nails
1m PVC pole (2/transect, 2/photo point)	Mangrove species plant list/guidebook
Camera and tripod	Appropriate clothing (rubber boots, hat, water, etc.)
Densitometer	Clinometer (with percent scale)

8.1.1.2 Fieldwork

<u>Steps for interrupted line transect method:</u>

1) Establish at least three transects that are at least 20 m apart for each site. Depending on the size of the site, the distance between each transect may be more or less than 20 m.
2) The starting point (0 m) of the transect line should begin at the edge of the terrestrial forests/upland and end at the seaward zone (near seawater).
3) After determining the starting and ending point of the transect, place a PVC pole at each end.
4) Record the GPS coordinates of starting and ending point for each transect on the data sheet.
5) Tie the 100 m transect tape to the PVC pole at the starting point and make sure it is secure. Then lay the transect tape at the ending point. Again, note that all transect lines must be perpendicular to the edge of water.
6) Walk along the transect line once to explore the environment surrounding each transect. Walk only on one side along the transect line to avoid trampling on vegetation to be sampled.
7) Repeat steps 1-6 to set up the remaining transect lines.

Monitoring steps for interrupted line transect:

Level 1 monitoring focuses primarily on mangrove species diversity are present in the site and the sites condition. Therefore, we will monitor only the species present and their growth forms. The interrupted line transect method monitors the species present along a certain interval of the transect line within each vegetation zone.

1) Record the monitoring period on the data sheet to indicate how long it has been after restoration. If it is the first monitoring of the site, put $\mathbf{T_0}$ (Time zero). If the second monitoring period takes place 3 months after the first monitoring period (T_0), put $\mathbf{T_0 + 3}$ **months** on the data sheet.
2) Walk along the transect line and record all the species present at each meter mark (1m interval). For longer transect lengths, other interval can be set to record the species present such as every other meter or at every 5m mark depending on the total length of the transect.
3) Record the species name(s) on the data sheet. Use the mangrove species guidebook to help identify each species.
4) Take a photo of and collect a sample of unidentifiable species in a ziplock bag and label the bag as "unknown" following by a number (e.g. unknown 1). Then bring it back with you to have it keyed out later by expert/botanist.
5) Observe the vegetation and record your observations on the data sheet.
6) Repeat steps 1-6 for other transect lines.

LEVEL 1 MONITORING DATA SHEET

Date: ____________ Transect #: ___________ Monitoring Interval: ___________

Site Name: ______________________ Monitoring Period: ______________________

Names of Data Collectors: ___________________________, ___________________________,

___________________________, ___________________________

Latitude of Transect Starting Point: ____________________________

Longitude of Transect Starting Point: ___________________________

Meter Mark	Mangrove Zonation	Species Present	Observation

Transect #: ___________________ Date: ___________________

Meter Mark	Mangrove Zonation	Species Present	Observation

Latitude of Transect Ending Point: ____________________________

Longitude of Transect Ending Point: ___________________________

Notes:

____

____

<u>Legend:</u>

Mangrove Zone = terrestrial forest (F), landward (L), mid (M), seaward (S)

SAMPLE

LEVEL 1 MONITORING DATA SHEET

Date: 4/26/14 Transect #: 1 Monitoring Interval: 1m

Site Name: Baan Talay Nok (BTN) Monitoring Period: To

Names of Data Collectors: Pim Lanlikitmont, ____________, ____________, ____________

Latitude of Transect Starting Point: 9° 24' 54.04" N

Longitude of Transect Starting Point: 98° 26' 33.15" E

Meter Mark	Mangrove Zonation	Species Present	Observation
1	L	Xylocarpus, Nypa	Healthy
2	L	Xylocarpus, Nypa	Healthy
3	L	Nypa	Healthy
4	L	Nypa	Dying
5	L	Nypa	Dying
6	M	Rhizophora	Healthy
7	M	Rhizophora, Bruguiera	Healthy
8	M	Bruguiera	Healthy
9	M	Bruguiera	Healthy
10	M	Ceriops, Bruguiera,	Healthy
		Rhizophora	Dying
11	S	Rhizophora	Healthy
12	S	Rhizophora	Healthy

SAMPLE

Transect #: 1 Date: 4/26/14

Meter Mark	Mangrove Zonation	Species Present	Observation
13	S	Bruguiera, Rhizophora	Healthy
14	S	Rhizophora, Avicennia	Healthy
15	S	—	—
16	S	—	—
17	S	—	—
18	S	Avicennia, Sonneratia	Just seedlings
19	S	Sonneratia	Seedlings
20	S	—	—

Latitude of Transect Ending Point: 9°24'53.64" N

Longitude of Transect Ending Point: 98°26'34.20" E

Notes:

Next monitoring period should be 3 months from today (T_0 + 3 months).

Legend:

Mangrove Zone = terrestrial forest (F), landward (L), mid (M), seaward (S)

8.1.2 Level 2: Permanent Plots

I recommend that Level 2 monitoring is used for evaluating restored mangrove community structure, tree height, tree diameter, and the density of seedlings. Level 2 monitoring should be done annually.

8.1.2.1 Planning and Preparation for Fieldwork

See section 7.1.1.1 for instructions.

8.1.2.2 Fieldwork

Conduct this monitoring along the same transects established in Level 1 Monitoring or see section 7.1.1.2 for setting up transect lines if Level 1 was not conducted at this site.

Identifying sampling points:

1) Use a surveying tape to measure the width of each mangrove zone and record it on the data sheet. Use zonation descriptions on p.18-19 to determine the characteristics of each zone (Figure 5). One way to identify the beginning and ending of a mangrove zone is when the dominant vegetation starts to change. For example, *Xylocarpus* spp. is one of the few dominant species in landward zone, *Rhizophora* spp. and *Ceriops* spp.ares common in the mid zone, and *Sonneratia* spp. is one of the dominant species in seaward zone.
2) After measuring the width of each zone, go to the center of each zone along the transect line and identify a sample location. Select an area for each plot that appears to be distinctive of each mangrove zone based on the aerial photo and also ask the expert on site for advice. Avoid picking unique areas that are close to tidal creek or development. Random numbers can be used to select sampling plots if areas are large enough.
3) Each plot established should be 10m x 10m in dimension. The plot size can be larger or smaller depending on the surrounding environment of the plot. If the trees are very dense, the dimension can be reduced to 5m x 5m. If the trees are very large, the dimension can be increased to 20m x 20m.
4) Mark the corners of each plot with a PVC pole marked with bright flagging tape.
5) Record the GPS coordinates for each corner of the plot on the data sheet.

6) Label the sampling plot according to the transect, mangrove zone, and plot number in that order. For example, plot 2 in the landward zone along transect 1 will be 1L2, plot 5 in the mid zone along transect 2 will be 2M5, and plot 1 in the seaward zone along transect 3 will be 3S1. Record the sampling plot ID on the data sheet.
7) With your monitoring team or partner, assess and record all the data required on the data sheet. Follow the instructions on how to monitor each parameter in the monitoring parameters section below.
8) Repeat steps 1-5 to identify the location of new sampling points for remaining transect lines.
9) You can add more plots along each transect to improve the accuracy or representativeness of your monitoring data.

Monitoring parameters:

Percent Cover

1) Estimate the total percent cover of vegetation within the three structural vegetation layers: 0-1 m, 1-3 m, and >3 m regardless of the growth form.
2) Use Table 6 to determine codes used to estimate vegetation aerial percent cover.
3) Record the percent cover on the data sheet.

Canopy Cover

1) A densitomer is used to determine the canopy cover. To calculate the average canopy cover, look through the densitometer and level it using the level bubble.
2) Estimate the percent of canopy cover that appears in the densitometer. A total of nine readings for each plot are needed to calculate the average canopy cover. See Figure 10 for the point where each reading should be done within the permanent plot.
3) Sum up the nine readings and divide it by nine to get an average canopy cover.

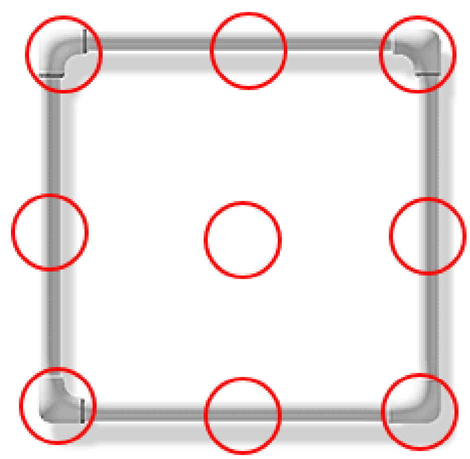


Figure 10. Nine canopy cover reading points.

4) Record the canopy cover on the data sheet and use the same vegetation cover codes from Table 6.

Table 6. Codes used to record vegetation aerial percent cover (Bucher et al. 2013, Coulloudon et al. 1999).

Code	Percent Cover (%)	Midpoint of Range (%)
0	0	0
1	1-5	2.5
2	5-25	15.0
3	25-50	37.5
4	50-75	62.5
5	75-95	85.0
6	95-100	97.5

Height

In mangrove ecosystems, seedlings are defined as individual trees <1.37 m in height. For initial monitoring stages, a telescoping measuring rod or measuring tape can be used to determine the height for the newly recruited mangrove species (Kauffman and Donato 2012). After a couple years when mangrove trees have grown, a clinometer and either survey tape or rangefinder can be used to measure the height of the tree.

1) Select a location where you can see both the top and bottom of the tree you are measuring.
2) Use tape measure to measure the distance between you and the tree.
3) Using a clinometer, take % readings for both the top of the tree and the bottom of the tree and record both readings on the data sheet.
4) Use this equation for calculate the height:
   top % - bottom % = total % height
   total % height x horizontal baseline distance - height
5) Use Table 7 to determine the height class of the tree on the data sheet.

Table 7. Height class for vegetation height (CNPS 2014 and Coffman 2012).

Height Class	1	2	3	4	5	6	7	8	9	10
Height (m)	<1/2	1/2-1	1-2	2-5	5-10	10-15	15-20	20-35	35-50	>50

Diameter Breast Height (DBH)

1) Measure the DBH for all mangrove trees that are higher than 1.4 m. DBH is used to monitor the growth of the tree and is usually measured in centimeters.
2) Measure the height of the tree from the ground with a measuring tape and mark at 1.4 m.
3) Hammer in a tag number for every tree in the plot that is taller than 1.4 m using a stainless steel nail and numbered tag so that we can come back and monitor the change in the next monitoring period. Also mark the tree with brightly colored flagging tape for easier visual.
4) After marking the 1.4 m height, use the same measuring tape to measure the circumference of the tree at 1.4 m or a get a direct measurement using DBH tape.
5) Use the following equation to calculate DBH:
   DBH = circumference/π
6) Record the DBH on the data sheet.

Growth Form

1) Record the growth form on the datasheet.
   According to the FAO Mangrove Guidebook for Southeast Asia by Giesen et al. (2006), there are seven groups of mangroves growth form:

   Group A: Ferns (including epiphytic ferns)

   Plants without flowers or stem. Plants in Group A typically have a woody, root-like rhizome upon which stiff leaf-stalks are directly planted.

   Group B: Grass-like plants

   Ground-dwelling herbs with long, linear leaves and inconspicuous flowers.

   Group C: Other ground-dwelling herbs

   Ground-dwelling herbs which are not grass-like. Leaves are not long or liner and usually have conspicuous flowers. Plants in Group C often have soft stems that are only occasionally woody and are not taller than 2 m in general.

   Group D: Epiphytes (other than ferns)

Plants which live on the surface of other plants, usually on trees or palms.

Group E: Vines and climbers

Woody or herbaceous plants that are not self-supporting but climbing or trailing on some support such as on trees and shrubs.

Group F: Palms, pandans, and cycads

Stem are woody, straight, and usually tall; unbranched up to the first leaves. Leaves are longer than 1 m and are usually divided into many leaflets.

Group G: Trees and shrubs

Large woody plants either with a single main stem or trunk (tree) or smaller with stems that divide into many stems (shrub). According to the U.S. Army Corps of Engineer (2008), tree have woody plants 3 in. (7.6 cm) or more in diameter breast height (DBH), regardless of height and shrub consists of woody plant less than 3 in. DBH, regardless of height.

Identify Mangrove Species

1) Use mangrove species list or guidebook to help identify the species present in each sampling point.
2) If you are not able to identify some of the species present, collect a sample of the unknown species (make sure to get a flower or fruit) and place it in a ziplock bag and take a photo of the unknown species.
3) Label the ziplock bag or photo as "unknown" followed by a number.
4) Record the unknown species on the data sheet according to the label on the ziplock bag or photo.
5) Show the collected unknown species and photo to a botanist to help key out the species as soon as possible

LEVEL 2 MONITORING DATA SHEET

Date: ______________ Transect # ____________ Site Name: _________________________ Monitoring Period: __________________

Plot ID: ____________________ Plot Dimension: ____________________ Mangrove Zone: ______________________

Names of Data Collectors: _______________________________, _______________________________, _______________________________

Latitude of Transect Starting Point: ____________________________ Latitude of Transect Ending Point: ____________________________

Longitude of Transect Starting Point: ___________________________ Longitude of Transect Ending Point: ___________________________

GPS Coordinates of Each Corner of Permanent Plot		
Corner #	**Latitude**	**Longitude**
1		
2		
3		
4		

Notes:

____

____

Plot ID: _______________ Date: __________________

Species Name	Growth Form	Height (m)	Height Class	DBH (cm)	Percent Cover (%)	Cover Class

Legend:

Mangrove Zone = terrestrial forest (F), landward (L), mid (M), seaward (S)

Growth Form = ferns (A), grass-like plants (B), other ground-dwelling plants (C), epiphytes (D), vines and climbers (E), palms, pandans, and cycads (F), trees and shrubs (G)

Cover Classes = 0: 0%, 1: 1-5%, 2: 5-25%, 3: 25-50%, 4: 50-75%, 5: 75-95%, 6: 95-100%

Height Class = 1: <1/2 m, 2: 1/2-1 m, 3: 1-2 m, 4: 2-5 m, 5: 5-10 m, 6: 10-15 m, 7: 15-20 m, 8: 20-35 m, 9: 35-50 m, 10: >50 m

SAMPLE

LEVEL 2 MONITORING DATA SHEET

Date: 4/26/14 Transect # 1 Site Name: Baan Talay Nok (BTN) Monitoring Period: To

Plot ID: 1S1 Plot Dimension: 10m x 10m Mangrove Zone: Seaward (S)

Names of Data Collectors: Pim Lalitkitnant, ______, ______

Latitude of Transect Starting Point: 9°24'54.04" N Latitude of Transect Ending Point: 9°24'53.64" N

Longitude of Transect Starting Point: 98°26'33.15" E Longitude of Transect Ending Point: 98°26'34.20" E

GPS Coordinates of Each Corner of Permanent Plot		
Corner #	Latitude	Longitude
1	9°24'53.88" N	98°26'33.09" E
2	9°24'53.54" N	98°26'33.03" E
3	9°24'53.42" N	98°26'33.33" E
4	9°24'53.72" N	98°26'33.42" E

Notes:

1S1 = Transect # 1, Seaward Zone, Plot # 1

SAMPLE

Plot ID: 1S1

Date: 4/26/14

Species Name	Growth Form	Height (m)	Height Class	DBH (cm)	Percent Cover (%)	Cover Class
Rhizophora mucronata	G	11	5	21	10	2
Avicennia germinans	G	3	4	14	20	2
Sonneratia caseolaris	G	1/2	2	—	5	1
Nypa fruticans	F	1	2	—	5	1

Legend:

Mangrove Zone = terrestrial forest (F), landward (L), mid (M), seaward (S)

Growth Form = ferns (A), grass-like plants (B), other ground-dwelling plants (C), epiphytes (D), vines and climbers (E), palms, pandans, and cycads (F), trees and shrubs (G)

Cover Classes = 0: 0%, 1: 1-5%, 2: 5-25%, 3: 25-50%, 4: 50-75%, 5: 75-95%, 6: 95-100%

Height Class = 1: <1/2 m, 2: 1/2-1 m, 3: 1-2 m, 4: 2-5 m, 5: 5-10 m, 6: 10-15 m, 7: 15-20 m, 8: 20-35 m, 9: 35-50 m, 10: >50 m

8.1.3 Level 3: Sedimentation Monitoring

Level 3 Monitoring focuses on the geomorphology of the restoration site. It helps determine if there has been sediment accretion or sediment erosion at the site. The ground surface becomes more stable as sediment accumulates and makes it better for mangrove species to grow on. Whereas, the ground surface becomes less stable during sediment erosion.

8.1.3.1 Planning and Preparation for Fieldwork

See section 7.1.1.1 for instructions.

8.1.3.2 Fieldwork

Level 3 can only be done after completing Level 2 monitoring once the permanent plot has been set up. Conduct this monitoring along the same transects established in Level 1 and Level 2 monitoring. The equipment required in addition to Table 5 for Level 3 monitoring are 1.5 m long narrow PVC pipes (10 per permanent plot), a survey/measuring tape, and a permanent marker to mark the sedimentation stakes.

<u>Steps for sedimentation monitoring:</u>

1) Select a location to place sedimentation stakes on along one side of the permanent plot. The location should be where the soil is undisturbed and unlikely to be stepped on.
2) Use a permanent marker to number and mark each sedimentation stake at 40 cm.
3) Use the 1.5 m long narrow PVC pipes as sedimentation stakes. Place the sedimentation stakes into the mud. Arrange 10 stakes in a row spaced 1 m apart along the permanent plot.
4) Push each sedimentation stake into the mud surface so that only 40 cm, marked in step 3, of the PVC pipe remain sticking out of the sediment surface.
5) Measure each stake facing one direction such as facing the seaward zone.
6) Use a measuring tape to measure the height of the sedimentation stake above the mud surface. For the first monitoring period, all measurements should be 40 cm. This value will either be higher or lower than 40 cm in the next monitoring period depending on sediment accretion or erosion.
7) Record the measurements of each sedimentation stake on the data sheet.
8) Repeat steps 1-7 for the remaining permanent plots.

LEVEL 3 MONITORING DATA SHEET

Date: ______________ Transect # ____________ Site Name: _________________________

Monitoring Period: __________________ Plot ID: _______________ Zone Facing: _______________

Names of Data Collectors: ______________________, ______________________, ______________________

Stake #	Height (cm)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Notes:

____

____

SAMPLE

LEVEL 3 MONITORING DATA SHEET

Date: 4/26/14 Transect # 3 Site Name: Baan Talay Nok (BTN)

Monitoring Period: To Plot ID: 3M1 Zone Facing: Seaward (S)

Names of Data Collectors: Pim Laulikitnant, ____________, ____________

Stake #	Height (cm)
1	40
2	40
3	40
4	40
5	40
6	40
7	40
8	40
9	40
10	40

Notes:

First monitoring period (To), it is normal and expected that every stake have the same height (40 cm).

SAMPLE

LEVEL 3 MONITORING DATA SHEET

Date: 4/26/15 Transect # 3 Site Name: BTN

Monitoring Period: To + 12 months Plot ID: 3M1 Zone Facing: Seaward (S)

Names of Data Collectors: Pim Lanlihithnart, ________, ________

Stake #	Height (cm)
1	31
2	33
3	36
4	42
5	41
6	45
7	43
8	43
9	44
10	48

Notes:

Example

8.1.4 Photo Monitoring

Photo monitoring monitors the overall change of the site over time. In this protocol, I propose a feature photo point monitoring method. This method documents visual changes occurring at a fixed point through time. This method is widely used for restoration projects. Photo monitoring should be done every six months.

8.1.4.1 Fieldwork

Setting up photo points:

1) Select a fixed location in the site that is the most representative. The most important criteria for establishing ideal photo point locations is to have adequate lightings to take the photo and the location must be accessible both before and after restoration.
2) Place one 1m PVC pole into the ground and mark with a brightly colored flagging tape. This will be your camera point or the point where you take the photo.
3) Record the GPS coordinates on the data sheet.
4) Place the second 1m PVC pole 5m apart from the camera point and also mark it with a brightly colored flagging tape. This will be your feature photo point.
5) Record the GPS coordinates on the data sheet.
6) Record the monitoring period on the data sheet to indicate how long it has been after restoration. If it is the first monitoring of the site, put $\mathbf{T_0}$ (Time zero) and T_0 + 6 months if the next monitoring period takes place 6 months after time zero.

Taking baseline photos:

1) Record the time and weather conditions on the data sheet. Always take photos when the sun is less intense such as early morning or late afternoon. Avoid taking photos when visibility is poor. There should be a distinctive landmark in the photo to help line up subsequent photos.
2) Record the type of camera/lens and the camera orientation on the data sheet and try to use the same camera for the next monitoring period but always take photos in the same orientation.
3) Set up a camera on the tripod at the camera point marked with the PVC pole.
4) Use a measuring tape to measure the height of the tripod and record it on the data sheet.
5) Take the picture of the site and make sure that photo point is marked with another PVC pole 5m apart is in the center of the photo.

PHOTO MONITORING DATA SHEET

Date: _____________ Time of Monitoring: ____________ Site Name: ______________________

Monitoring Period: ______________ Camera Model: ____________ Tripod Height: _____________

Camera Orientation: ___________ Weather Condition: ____________ Direction Facing: ___________

Names of Data Collectors: ____________________, ____________________, ____________________

GPS Coordinates of Each Photo Monitoring Points		
	Latitude	**Longitude**
Camera Point		
Photo Point		

[ATTACH PHOTO HERE]

SAMPLE

PHOTO MONITORING DATA SHEET

Date: 4/26/13 Time of Monitoring: 8:15 AM Site Name: Baan Talay Nok (BTN)

Monitoring Period: To Camera Model: Canon EOS Tripod Height: 1.5 m

Camera Orientation: Landscape Weather Condition: Sunny Direction Facing: S

Names of Data Collectors: Pim Lanlithitmant ____, ____

GPS Coordinates of Each Photo Monitoring Points		
	Latitude	Longitude
Camera Point	9°24'55.86"N	98°26'7.77"E
Photo Point	9°24'55.88"N	98°26'7.61"E

SAMPLE

PHOTO MONITORING DATA SHEET

Date: 10/26/13 Time of Monitoring: 9:30 AM Site Name: Baan Talay Nok (BTN)

Monitoring Period: To +6 months Camera Model: Canon EOS Tripod Height: 1.5 m

Camera Orientation: Landscape Weather Condition: Sunny Direction Facing: S

Names of Data Collectors: Pim Lanlikitrant, ________, ________

GPS Coordinates of Each Photo Monitoring Points		
	Latitude	Longitude
Camera Point	9°24'55.86" N	98°26'7.77" E
Photo Point	9°24'55.88" N	98°26'7.61" E

LITERATURE CITED

Ambrose, R. F., and S. F. Lee. 2007. An evaluation of compensatory mitigation projects permitted under Clean Water Act Section 401 by the California State Water Resources Control Board, 1991-2002. Final Report.

Barbier, E. B., and M. Cox. 2004. An economic analysis of shrimp farm expansion and mangrove conversion in Thailand. Land Economics **80**:389–407.

Biswas, S. R., A. U. Mallik, J. K. Choudhury, and A. Nishat. 2008. A unified framework for the restoration of Southeast Asian mangroves—bridging ecology, society and economics. Wetlands Ecology and Management **17**:365–383.

Bovell, O. 2011. Guyana mangrove nursery manual. Guyana Mangrove Restoration Project, Georgetown, Guyana.

Bucher, D., M. Baronio, and D. Stokes. 2013. Monitoring mangrove condition: Gladstone Harbor, Fishermans Landing - March 2013. Southern Cross University, New South Wales, Australia.

California Native Plant Society. Protocol for combined vegetation rapid assessment field survey and relevé sampling field form. U.S. Department of the Interior, U.S. Fish and Wildlife Service, Sacramento, California, USA.

Callaway, J. C., and J. B. Zedler. 2009. Conserving the diverse marshes of the Pacific Coast. Pages 285–308 *in* B. R. Silliman, E. Grosholz, and M. D. Bertness. Human impacts on salt marshes: a global perspective. University of California Press, Berkeley, California, USA.

Clewell, A., J. Rieger, and J. Munro. 2005. Guidelines for developing and managing ecological restoration projects. 2nd edition. Society for Ecological Restoration International.

Coffman, G. C. 2012. Redwook creek restoration revegetation monitoring. University of San Francisco, San Francisco, California, USA.

Coulloudon, B. 1999. Sampling vegetation attributes. Technical Reference BLM/RS/ST-96/002+1730. U.S. Department of the Interior, U.S. Bureau of Land Management. Denver, Colorado, USA.

Ellison, A. M. 2000. Mangrove restoration: do we know enough? Restoration Ecology **8**:219–229.

Ellison, J., V. Jungblut, P. Anderson, and C. Slaven. 2012. Manual for mangrove monitoring in the Pacific Islands Region. Secretariat of the Pacific Regional Environmental Programme, Apia, Samoa.

Elster, C. 2000. Reasons for reforestation success and failure with three mangrove species in Colombia. Forest Ecology and Management **131**:201–214.

Elzinga, C. L., D. W. Salzer, and J. W. Willoughby. 1998. Measuring and monitoring plant populations. BLM/RS/ST-98/005+1730. U.S. Department of the Interior, U.S. Bureau of Land Management, National Business Center, Denver, Colorado, USA.

Erftemeijer, P. L. A., and R. R. Lewis III. 2000. Planting mangroves on intertidal mudflats: habitat restoration or habitat conversion? Pages 156-165 *in* Proceedings of the ECOTONE VIII Seminar Enhancing Coastal Ecosystems Restoration for the 21st Century, Ranong, Thailand, May 23-28, 1999. Royal Forest Department of Thailand, Bangkok, Thailand.

Feller, I. C., and M. Sitnik. 2003. Mangrove ecology workshop manual. Smithsonian Institution Scholarly Press, Washington, D.C., USA.

Field, C. D. 1998. Rehabilitation of mangrove ecosystems: an overview. Marine Pollution Bulletin **37**:383–392.

Giesen, W., S. Wulffraat, M. Zieren, and L. Scholten. 2006. Mangrove guidebook for Southeast Asia. RAP Publication 2006/07. Food and Agriculture Organization of the United Nations and Wetlands International, Bangkok, Thailand.

Giri, C., Z. Zhu, L. L. Tieszen, A. Singh, S. Gillette, and J. A. Kelmelis. 2008. Mangrove forest distributions and dynamics (1975–2005) of the tsunami-affected region of Asia. Journal of Biogeography **35**:519–528.

Giri, C., E. Ochieng, L. L. Tieszen, Z. Zhu, A. Singh, T. Loveland, J. Masek, and N. Duke. 2011. Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecology and Biogeography **20**:154–159.

Holl, K. D., and J. Cairins Jr. 2002. Monitoring and appraisal. Pages 410-429 *in* M. R. Perrow and A. J. Davy, editors. Handbook of ecological restoration. Cambridge University Press, New York, New York, USA.

Kairo, J. G. 2001. Ecology and restoration of mangrove systems in Kenya. Dissertation. Vrije Universiteit Brussel, Brussels, Belgium.

Kairo, J. G., J. Bosire, and N. Koedam. 2001. Restoration and management of mangrove systems – a lesson for and from the East African region. South African Journal of Botany **67**:383–389.

Kamali, B., and R. Hashim. 2008. Mangrove restoration without planting. Ecological Engineering **37**:387–391.

Kamthonkiat, D., C. Rodfai, A. Saiwanrungkul, S. Koshimura, and M. Matsuoka. 2011. Geoinformatics in mangrove monitoring: damage and recovery after the 2004 Indian Ocean tsunami in Phang Nga, Thailand. Natural Hazards and Earth System Science **11**:1851–1862.

Kauffman, J. B., and D. C. Donato. 2012. Protocols for the measurement, monitoring and reporting of structure, biomass, and carbon stocks in mangrove forests. Working Paper 86. CIFOR, Bogor, Indonesia.

Lewis III, R. R. 1999. Key concepts in successful ecological restoration of mangrove forests. Pages 19-32 *in* Proceedings of the TCE-Workshops No. II, Coastal Environmental Improvement in Mangrove/Wetland Ecosystems, Bangkok, Thailand, August 18-23, 1998. Danish-SE Asian Collaboration in Tropical Coastal Ecosystems (TCE) Research and Training, Bangkok, Thailand.

Lewis III, R. R. 2000. Ecologically based goal setting in mangrove forest and tidal marsh restoration. Ecological Engineering **15**:191–198.

Lewis III, R. R. 2001. Mangrove restoration - costs and benefits of successful ecological restoration. Pages 1-18 *in* Proceedings of the Mangrove Valuation Workshop, Penang, Malaysia, April 4-8, 2001. Beijer International Institute of Ecological Economics, Stockholm, Sweden.

Lewis III, R. R. 2005. Ecological engineering for successful management and restoration of mangrove forests. Ecological Engineering **24**:403–418.

Lewis III, R. R. 2009. Mangrove field of dreams: if we build it, will they come? SWS Research Brief **5**:1–4.

Lewis III, R. R. 2011. How successful mangrove forest restoration informs the process of successful general wetland restoration. National Wetlands Newsletter **33**:23–25.

Lewis III, R. R., A. B. Hodgson, and G. S. Mauseth. 2005. Project facilitates the natural reseeding of mangrove forests (Florida). Ecological Restoration **23**:276–277.

Lewis III, R. R., and R. G. Gilmore. 2007. Important considerations to achieve successful mangrove forest restoration with optimum fish habitat. Bulletin of Marine Science **80**:823–837.

Loyche, M. 1989. Mangrove of West Africa - the forest within the sea. Mangrove and Fish. IDAF Newsletter **9**: 18–31.

Mangrove Action Project. 2007. Six steps to successful mangrove forest restoration emphasizing the hydrologic restoration methodology. Mangrove Action Project, Port Angeles, Washington, USA.

Mangrove Action Project. 2013. Mangrove conservation and restoration. <http://mangroveactionproject.org/conservation-restoration/>

McKee, K. L., and P. L. Faulkner. 2000. Restoration of biogeochemical function in mangrove forests. Restoration Ecology **8**:247–259.

NOAA Restoration Center and NOAA Coastal Services Center. 2010. Returning the tide, a tidal hydrology restoration guidance manual for the southeastern U.S. NOAA, Silver Spring, Maryland, USA.

Northern Territory Government. 2002. Mangrove management in the Northern Territory. Northern Territory Government, Department of Infrastructure, Planning, and Environment, Palmerston, Northern Territory, Australia.

Odum, W. E., C. C. McIvor, and I. J. Smith III. 1982. The ecology of the mangroves of South Florida: a community profile. FWS/OBS-81/24. U.S. Department of the Interior, U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C., USA.

Pastorok, R. a, A. MacDonald, J. R. Sampson, D. J. Yozzo, and J. P. Titre. 1997. An ecological decision framework for environmental restoration projects. Ecological Engineering **9**:89–107.

Primavera, J. H., and J. M. a. Esteban. 2008. A review of mangrove rehabilitation in the Philippines: successes, failures and future prospects. Wetlands Ecology and Management **16**:345–358.

Quarto, A. 2007. Ecological mangrove restoration: workshop series. Pages 1-20 *in* Proceedings of the National Ecological Mangrove Restoration - Technical Training Workshop Program, Tangalle, Sri Lanka, February 5-9, 2007. Mangrove Action Project, Port Angeles, Washington, USA.

Quarto, A. 2013. Ecological mangrove restoration (EMR): re-establishing a more biodiverse and resilient coastal ecosystem with community participation. Mangrove Action Project, Port Angeles, Washington, USA.

Ravishankar, T. and R. Ramasubramanian. 2004. Manual on mangrove nursery techniques. M.S. Swaminathan Research Foundation, Chennai, India.

Rönnbäck, P., B. Crona, and L. Ingwall. 2007. The return of ecosystem goods and services in replanted mangrove forests: perspectives from local communities in Kenya. Environmental Conservation **34**:313–324.

Ruiz-jaen, M. C., and T. M. Aide. 2005. Restoration success: how is it being measured? Retoration Ecology **13**:569–577.

Samson, M. S., and R. N. Rollon. 2008. Growth performance of planted mangroves in the Philippines: revisiting forest management strategies. Ambio **37**:234–240.

Sanyal, P. 1998. Rehabilitation of degraded mangrove forests of the Sunderbans of India. Pages 1-25 *in* Proceedings of the International Workshop on Rehabilitation of Degraded Coastal Systems, Phuket, Thailand, January 19-24, 1998. Phuket Marine Biological Center, Phuket, Thailand.

Sathirathai, S., and E. B. Barbier. 2001. Valuing mangrove conservation in Southern Thailand. Contemporary Economic Policy **19**:109–122.

Shaff, C., J. Reiher, and J. Campbell. 2007. OWEB guide to photo point monitoring. Oregon Watershed Enhancement Board, Salem, Oregon, USA.

Stone, K., M. Bhat, R. Bhatta, and A. Mathews. 2008. Factors influencing community participation in mangroves restoration: a contingent valuation analysis. Ocean & Coastal Management **51**:476–484.

Turner, R. E., and R. R. Lewis III. 1997. Hydrologic restoration of coastal wetlands. Wetlands Ecology and Management **4**:65–72.

Twilley, R. R., V. H. Rivera-Monroy, R. Chen, and L. Botero. 1998. Adapting an ecological mangrove model to simulate trajectories in restoration ecology. Marine Pollution Bulletin **37**:404–419.

U.S. Army Corps of Engineers. 2008. Regional supplement to the Corps of Engineers wetland delineation manual: arid west region (version 2.0). ERDC/EL TR-08-28. U.S. Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, Massachusetts, USA.

U.S. Department of the Interior. 2010. Adaptive Management. < http://www.doi.gov/archive/initiatives/AdaptiveManagement/>

Vaiphasa, C., W. F. de Boer, A. K. Skidmore, S. Panitchart, T. Vaiphasa, N. Bamrongrugsa, and P. Santitamnont. 2007. Impact of solid shrimp pond waste materials on mangrove growth and mortality: a case study from Pak Phanang, Thailand. Hydrobiologia **59**1:47–57.

Valiela, I., J. L. Bowen, and J. K. York. 2001. Mangrove forests: one of the world's threatened major tropical environments. BioScience **51**:807–815.

Watson, J.G. 1928. Mangrove forests of the Malay Peninsula. Malayan Forest Records No. 6. Forest Department, Federated Malay States, Kuala Lumpur, Malaysia.

Waycott, M., L. J. McKenzie, J. E. Mellors, J. C. Ellison, M. T. Sheaves, C. Collier, A. Schwarz, A. Webb, J. E. Johnson, and C. E. Payri. 2011. Vulnerability of mangroves, seasgrasses, and intertidal flats in the tropical Pacific to climate change. Pages 297-367 *in* Bell, J. D., J. E. Johnson, and A. J. Hobday, editors. Secretariat of the Pacific Community, Noumea, New Caledonia.

Wetlands Reserve Program. 2000. Restoration of mangrove habitat. Technical Note ERDC TN-WRP-VN-RS-3.2. U.S. Department of Defense. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi, USA.

Wortley, L., J.-M. Hero, and M. Howes. 2013. Evaluating ecological restoration success: a review of the literature. Restoration Ecology **21**:537–543.